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AlignCT: Fine alignment for x-ray computed tomography systems

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Disclaimer

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AlignCT: Fine alignment for x-ray computed tomography systems

Project Overview

The AlignCT project has established a protocol for aligning x-ray computed tomography (CT) systems, which combines high precision radiography phantoms and software alignment algorithms.

Project Goals

It is essential for x-ray computed tomography (CT) systems to know the exact trajectory of every ray as it passes through the object. Small misalignments or incorrect distances can quickly degrade the reconstructed contrast and resolution. To operate at peak performance, our CT systems undergo a manually intensive periodic alignment process, which relies on measuring the external distances between components. This process is time intensive and relies heavily on radiographer expertise and system dependent proprietary information.

An improved process needs to be able to determine both the general system geometry as shown in Figure 1, and any misalignments in the detector panel, alignment phantom, staging, and x-ray source. This requires computing the relative location and orientation of the panel and tomography stage (12 parameters).

Relevance to Lab Mission

X-ray CT provides critical characterization and validation for multiple Strategic Focus Areas. Improving the accuracy of existing systems advances the ST&E Materials on Demand roadmap goal by providing (a) better data for the validation of predictive modeling and (b) more accurate characterization of engineered or synthesized materials. The project also supports Engineering's core competencies in (a) non-destructive characterization and (b) signal/image processing and control.

FY12 Accomplishments

Major accomplishments for the project include the fabrication of precision phantoms; the implementation, testing, and validation of alignment algorithms; and the development of a protocol for testing, correcting, and tracking the alignment of our x-ray CT systems.

The design of the LLNL alignment phantom is based on a customized version of existing radiography phantoms [1-3]. The easily fabricated design consists of cylindrical Plexiglas shell embedded with a column of stainless steel balls, as shown in Figure 2. To accommodate different length scales, two phantoms were used: a larger 10 cm phantom with 1 mm balls and a smaller 1 cm phantom with 100 µm balls.

The software analysis package consists of two modules written in Matlab: a tracking routine that locates the ball centroids in each projection, and a geometry estimation routine that can work with an arbitrary object distribution. The tracking routine was tested under various contrast and misalignment scenarios, and was able to successfully trace the orbit of each ball in the presence of moderate misalignments (<5°). Initial system geometry is estimated from the parallax-induced elliptical orbits observed in Figure 3. This estimate is refined by fitting the forward model for a misaligned system to the observed data, after which corrective instructions are displayed for the radiographer.

A graphical user interface was constructed for the Matlab functions and compiled as a stand-alone executable. Figure 4 shows a comparison between a manual alignment and 2 iterations using the phantom based alignment.

The previous time-intensive manual alignment process was able to level the panel to within 0.04°, adjust the up/down tilt to within 1.0°, and adjust the left/right slant to within 1.5°. With the phantom, these misalignments were reduced to 0.003°, 0.006°, and 0.08°, respectively. This reduced the peak error from 6.5 pixels to 0.15 pixels. For an object near the edges of the CT volume, this reduces the misalignment induced blurring from 3 pixels to < 0.1 pixel.

References

1. Chetley Ford, J., Zheng, D. & Williamson, J. F. Estimation of CT cone-beam geometry using a novel method insensitive to phantom fabrication inaccuracy: Implications for isocenter localization accuracy. *Medical Physics* **38**, 2829 (2011).

2. Noo, F., Clackdoyle, R. & Mennessier, C. Analytic method based on identification of ellipse parameters for scanner calibration in cone-beam tomography. *Physics in medicine …* **3489**, (2000).

3. Mennessier, C., Clackdoyle, R. & Noo, F. Direct determination of geometric alignment parameters for cone-beam scanners. *Physics in medicine and biology* **54**, 1633–60 (2009).

Illustrations

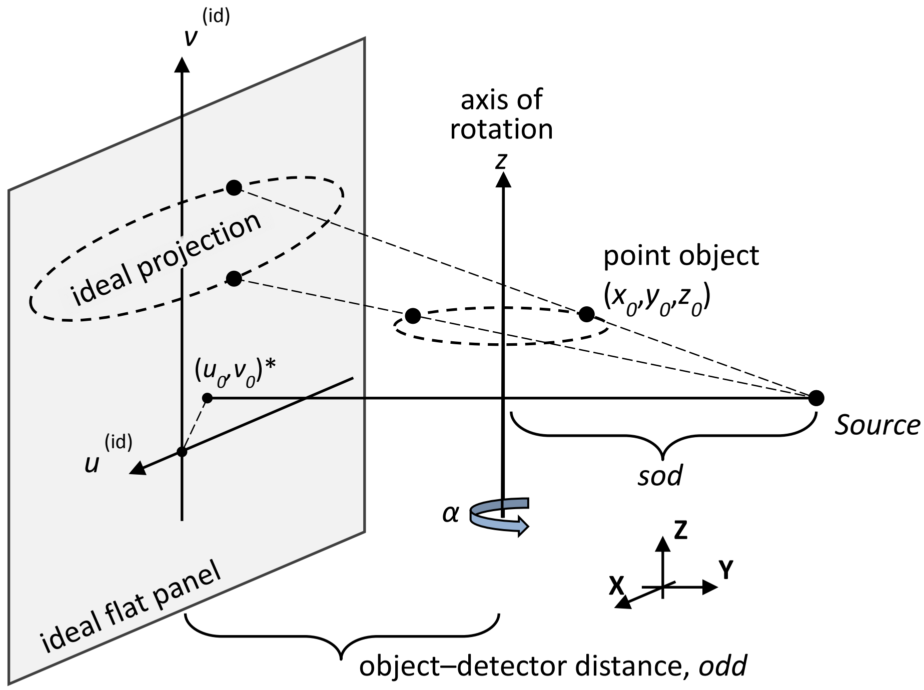

Figure 1. The experimental setup for the perfectly aligned x-ray computed tomography system. assumed by CT reconstruction algorithms. The central ray extends from the source and intersects the rotation axis at right angles. If the panel is not perpendicular to the central ray, then the measured projection of a point will differ from the expected, which degrades the reconstruction resolution and contrast.

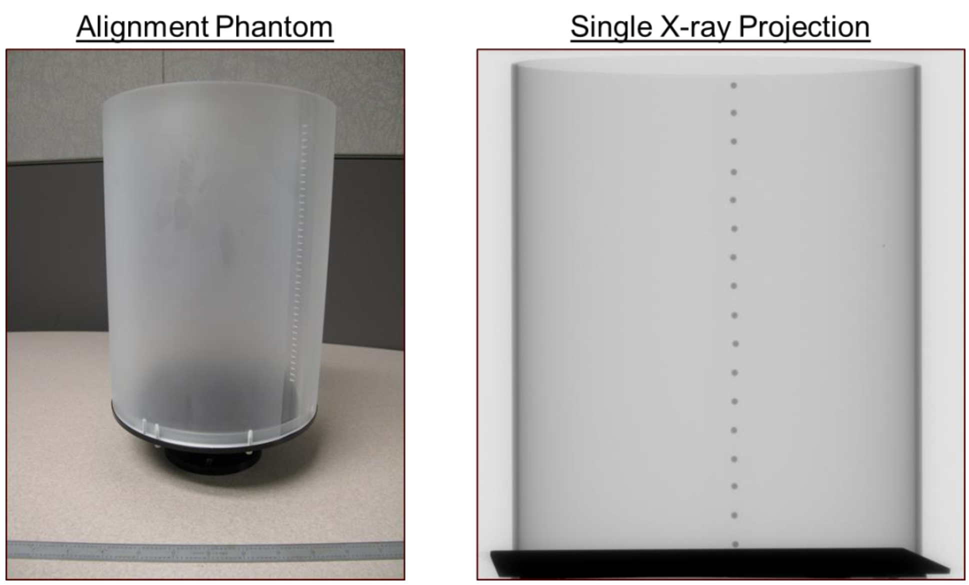

Figure 2. The left panel shows the alignment radiography phantom. The right panel shows a single x-ray projection form the dataset. The vertical column of steel balls is visible in the center of the phantom.

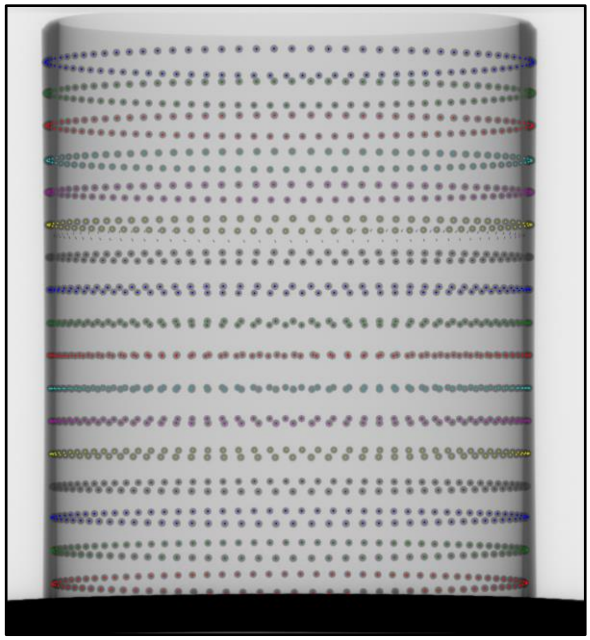

Figure 3. Blend of 90 projections acquired over 360°. The centroid of each ball has been marked by the alignment software.

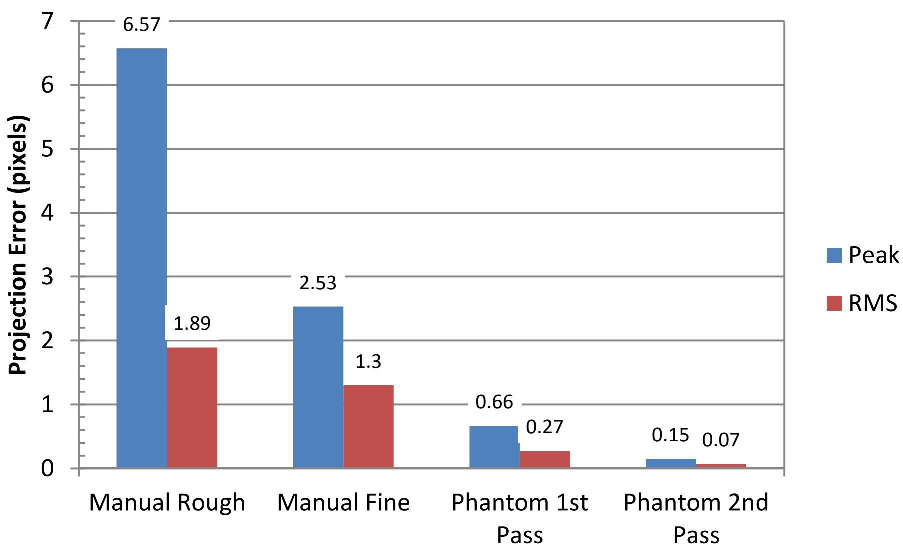

Figure 4. The measured alignment error after each stage. The error measures the distance between a ball centroid in the misaligned coordinates and in ideal coordinates assuming no panel misalignments.